Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 63 (2014) 5479 – 5482

Energy Procedia

GHGT-12

Comparison of the mineral trapping capacity in three reservoirs with variable mineral compositions under CO_2 saturated conditions

Ralf R. Haese[a,b], M. Watson[a]

[a] *Cooperate Research Centre for Greenhouse Gas Technologies, CO2CRC Ltd., Canberra, Australia*
[b] *Peter Cook Centre for CCS Research, University of Melbourne, Melbourne, Australia*

Abstract

The mineral trapping capacity is considered the most secure long-term CO_2 storage mechanism as it permanently demobilizes injected carbon. Here we compare three different reservoir rock mineral compositions in terms of their mineral trapping capacity using a mass balance approach. The evolution of carbon fractions in the form of residual CO_2, CO_2 in the formation water and carbon stored in minerals is predicted over time using reaction path modelling. The two studied siliciclastic reservoirs (Precipice Sandstone, Surat Basin, Australia; Pretty Hill Formation, Otway Basin Australia) have no or only a very small mineral trapping capacity, whereas the volcanoclastic reservoir (Takinoue Formation, central Hokkaido, Japan) has a very large mineral trapping capacity. This difference results from the abundance of reactive Ca-, Mg- and Fe-bearing silicate minerals. It is demonstrated that the mineral trapping capacity of volcanoclastic rocks can exceed residual and solubility trapping. The limitation of the chosen approach is a rather simplistic treatment of mineral dissolution and precipitation kinetics.

Peer-review under responsibility of the Organizing Committee of GHGT-12

Keywords: CCS; geochemical modelling; fluid rock interactions; mineral trapping capacity

1. Introduction

Estimating changes in structural, fluid, residual and mineral trapping capacity over time is an important aspect of the CO_2 storage site characterisation. It contributes to understanding the long-term fate of CO_2 under storage conditions and associated risks. The precipitation of carbonate minerals from injected CO_2 is referred to as mineral trapping and is considered the safest trapping mechanism. Determining the mineral trapping capacity requires accurate prediction of the fluid-rock reaction pathways and rates, which depend on the fluid composition, the mineralogy and kinetic properties including the mineral specific reactive surface area.

* Corresponding author. Tel.: +61-3-90353055; fax: +61-3-83447761.
E-mail address: ralf.haese@unimelb.edu.au

Peer-review under responsibility of the Organizing Committee of GHGT-12
doi:10.1016/j.egypro.2014.11.579

Predicting the dynamics of CO_2 trapping through the different trapping mechanisms for a CO_2 storage site requires reactive transport modelling at reservoir scale. The model results are inherently dependent on the representation of reservoir heterogeneity in terms of petrophysical properties such as permeability and mineralogy and the chosen operational conditions such as grid size. Independently, the scope of this study is limited to the role of the reservoir mineralogy in determining the mineral trapping capacity.

Here we take a mass balance approach for carbon present in the form of supercritical (residual) CO_2 (sc-CO_2), dissolved inorganic carbon (DIC) and mineral-bound carbon (min-C) and assess the abundance of carbon within the different fractions over time for different reservoir mineral compositions. This situation applies to the part of the reservoir which is water saturated and contains residual CO_2 after the termination of CO_2 injection. Initial conditions include the estimate of sc-CO_2, DIC controlled by the CO_2 saturation concentration and min-C given by the reservoir mineralogy. Dissolution and precipitation reactions are predicted using a kinetic reaction path modelling approach using The Geochemist Workbench™ software.

2. Materials and methods

In order to elucidate differences in model outcomes solely controlled by differences in the mineralogy, a generic formation water analogous to the Utsira Formation water composition at the Sleipner site was used. The same porosity (15%), pressure and temperature conditions and kinetic properties were chosen for each scenario. A residual CO_2 gas saturation of 20% was assumed. The mineral composition from the following three distinctively different reservoirs was chosen:

1. The Precipice Sandstone, Surat Basin (Queensland, Australia). The Precipice Sandstone is a fine to coarse grained quartzose sandstone deposited under fluvial-lacustrine conditions during the Early Jurassic. The Precipice Sandstone is recognised as a highly prospective CO_2 storage reservoir for Australia. Its mineralogy consists by enlarge of 96 and 4 vol% of quartz and kaolinite, respectively. Traces of siderite were occasionally identified in thin sections.

2. The Pretty Hill Formation, Otway Basin (Victoria / South Australia, Australia). The Pretty Hill Formation was deposited in a braided fluvial paleoenvironment during an early syn-rift phase of the Early Cretaceous Otway Basin. Its mineralogy is variable and complex with a characteristically high proportion of altered volcanic rock fragments. Faulting has significantly compartmentalised the Otway Basin with the result of local hydrocarbon accumulations and the exposure of the Pretty Hill Formation to highly variable CO_2 concentrations. The latter makes it a prime candidate for natural analogue studies. The representative mineralogy of the Pretty Hill Formation for this study is based on rocks which have not been exposed to significant levels of CO_2. The derived representative rock composition is: 60 vol% quartz, 19 vol% of albite, 10 vol% chlorite, 4.5 vol% calcite and minor (<2 vol%) amounts of K-feldspar, smectite, illite and kaolinite.

3. One of the targeted CO_2 storage reservoirs of the Tomakomai demonstration site in central Hokkaido, Japan, is the andesite-dominated Takinoue Formation (Okamura et al., 2010). Andesite is typically dominated by plagioclase and pyroxene minerals. In the absence of available mineral composition data, the abundance of minerals was estimated from the geochemical composition of the Takinoue Formation (Okamura et al., 2010) using the LPNORM software (de Caritat et al., 1994). The derived mineral composition is: 33 vol% plagioclase, 23 vol% pyroxene, 22 vol% kaolinite, 12 vol% chlorite and 10 vol% quartz.

Reaction path modelling was carried out using The Geochemist Workbench™ with the thermodynamic database thermo.dat. Kinetic properties were derived from Palandri and Kharaka (2004) and reactive surface areas of 10 and 70 cm^2/g were assigned to framework minerals and clay and carbonate minerals, respectively. The dissolved CO_2 concentration was fixed over time at the CO_2 saturation concentration at 60 ºC, a pressure of 150 bar and the total dissolved solid concentration of the Utsira formation water (close to 35,000 mg/L). In the Takinoue Formation, plagioclase was assumed to be composed of equal amounts of albite and anorthite and the pyroxene is assumed to be

composed of equal amounts of diopside and hedenbergite.

3. Results and discussion

The Precipice Sandstone has effectively no mineral trapping capacity (data not shown), because quartz dissolves only slowly and the mobilised Si does not contribute to carbonate precipitation. Dawsonite precipitation is here regarded as unrealistic based on the lack of evidence from natural analogue studies. In case of the Pretty Hill Formation with considerable amounts of reactive minerals such as albite, chlorite and calcite significant net carbonate precipitation occurs. Calcite serves as a source of Ca and chlorite serves as a source of Mg and Fe leading to the precipitation of ankerite ($CaFe(CO_3)_2$) and dolomite ($CaMg(CO_3)_2$) (Figure 1). The model results compare very well with the CO_2 altered analogues in the Otway Basin region. Overall, we find 3663 g of carbon precipitated as compared to 4582 and 22,826 g carbon stored as dissolved inorganic carbon and as residual CO_2, respectively, in one cubic meter of rock after 1000 years. Minor concentrations of calcite (< 1 vol%) are typically not detected by XRD, but significantly buffer the solution over very long time and thereby decrease mineral dissolution rates and control precipitation reactions. The volcanoclastic Takinoue Formation contains abundant Ca-, Fe-, and Mg-bearing reactive silicate minerals of the pyroxene and plagioclase groups leading to relatively rapid dissolution – precipitation reactions and a particularly high mineral trapping capacity. Pyroxene minerals would be depleted within approximately 25 years according to the modelling results, however, the overgrowth of authigenic minerals onto mineral surfaces is not accounted for, therefore, the rate of reactive mineral dissolution is likely grossly overestimated. Secondly, the dissolved CO_2 concentration is fixed throughout time, which is unrealistic in this case, as the pool of available carbon for carbonate mineral precipitation is limited by the amount of initial dissolved inorganic and residual carbon. In fact, the combined carbon mass of the latter two fractions is converted into mineralised carbon within less than 20 years.

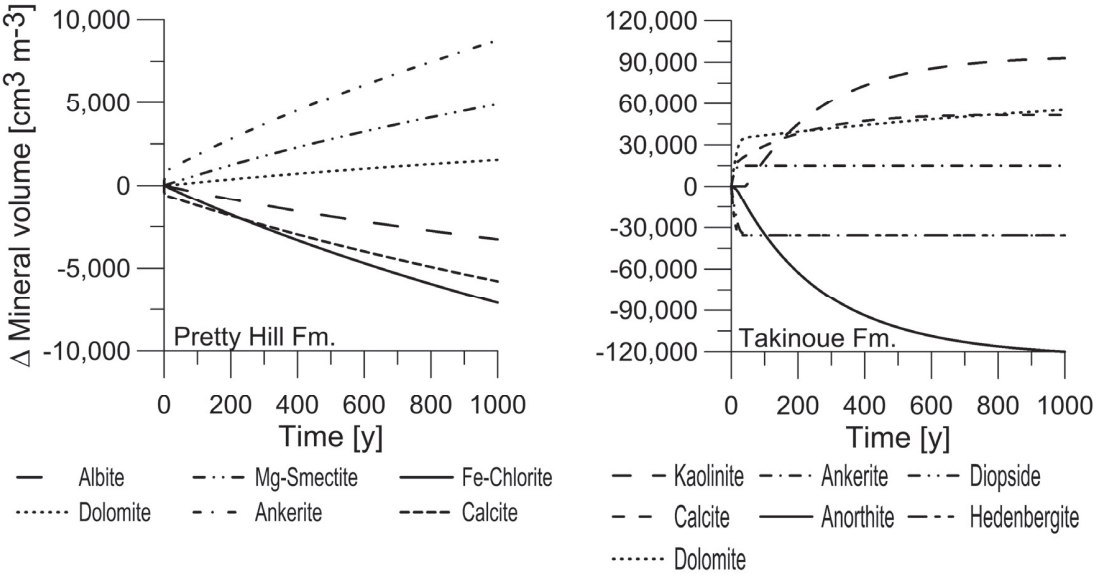

Figure 1: Predicted changes in mineral abundances for the siliciclastic Pretty Hill Formation (Otway Basin, Australia) and the volcanoclastic Takinoue Formation (Hokkaido Island, Japan). Note the rapid loss of the pyroxene minerals diopside and hedenbergite and respective precipitation of mixed Ca-, Mg- and Fe-carbonates in the Takinoue Formation.

4. Conclusions

While the limitations of this straight-forward mass balance approach do not allow for a representative quantification of carbon mineralisation, it does illustrate important differences in the carbon mineralisation capacity between siliciclastic reservoirs and even greater differences between siliciclastic and volcanoclastic reservoir rocks. The abundance and reactivity of Ca-, Mg-, and Fe-bearing silicate minerals together with the presence of (minor amounts of) calcite buffering the pH in solution are the primary factors controlling the mineral trapping capacity.

5. References

De Caritat P., Bloch J. and Hutcheon I., 1994, LPNORM: A linear programming normative analysis code. Comp. & Geosci. 20, 313-347.

Okamura S., Yahata M., Nishido H., Ibusuki A., Yokoi S., Yonejima M., Imayama T. and Maeda J., 2010, K-Ar ages and petrology of the Takinoue stage of volcanic rocks in the central Hokkaido, Japan: Geochemistry of volcanic rocks that form a shallow reservoir in the Yufutsu Oil and Gas Field. Jour. Geol. Soc. Japan 116, 181-198.

Palandri J.L. and Kharaka Y.K., 2004, A compilation of rate parameters of water mineral interaction kinetics for application to geochemical modelling. USGS Report 2004-1068, 64pp.

Acknowledgements

The authors wish to thank the Cooperative Research Centre for Greenhouse Gas Technologies, CO2CRC, for sponsoring this research and acknowledge the funding provided by the Commonwealth of Australia, State governments, industry and academic partners through the CO2CRC Program. Furthermore, we acknowledge financial assistance provided through Australian National Low Emissions Coal Research and Development (ANLEC R&D). ANLEC R&D is supported by Australian Coal Association Low Emissions Technology Limited and the Australian Government through the Clean Energy Initiative.